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# FLUCTUATING PRESSURES IN FLOW FIELDS OF JETS

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# FLUCTUATING PRESSURES IN FLOW FIELDS OF JETS

By James C. Schroeder and John K. Haviland

## INTRODUCTION

The powered-lift configurations under present development for STOL aircraft are the externally blown flap (EBF), involving direct jet impingement on the flaps, and the upper surface blown (USB), where the jet flow is attached on the upper surface of the wing and directed downward. The overall objectives of this research project are to develop scaling laws for the prediction of the unsteady loads imposed on the flaps and airfoil surfaces of these STOL aircraft. The goal is to develop theories for the prediction of fluctuating pressures on the aircraft structural components, and to develop test conditions under which these scaling laws can be investigated.

## CONTENTS

(Figure 1)

The objectives (fig. 1) of this phase of research were to develop methods of data acquisition and use these techniques to investigate the near-field fluctuating pressure behavior for the simplified cases of a round cold free jet and the same jet impinging on a flap plate. Techniques for using pressure sensitive probes were developed, together with digital analysis techniques. The quantities measured were $P_{rms}$ levels, 1/3-octave spectra, autocorrelations, and cross-correlations. Spectral densities, correlation coefficients, phase lags, and coherences

were calculated through the use of a computer program developed to analyze the output of the correlator.

This paper contains examples of coherence, phase lag (giving convection velocities) and overall fluctuating pressure levels behind the free jet and the same jet impinging on a flat plate. The fluctuating pressure levels measured are compared to levels measured on full-scale tests.

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- PLATE IMPINGEMENT FLUCTUATING PRESSURES
  - VARY DOWNSTREAM LOCATION; X/D
  - VARY IMPINGEMENT ANGLE; $\beta$
  - COHERENCE AND PHASE
  - CONVECTION VELOCITIES
  - OVERALL $P_{rms}$ LEVELS
- SCALING STUDY

Figure 1

## PRESSURE SENSORS AND INSTRUMENTATION

(Figure 2)

Figure 2 shows the fluctuating pressure sensors constructed for this investigation and a schematic representation of the data acquisition and analysis equipment used.

Two identical probes were used to measure fluctuating "static" pressures behind the free jet with minimal flow disturbance. The probes have a graduated outside diameter varying from 0.05 in. at the tip to 0.187 in. at the base. Four pressure sensing holes, 0.02 in. in diameter, are located 0.5 in. from the tip. These probes were then connected to 1/8 in. B & K condensor microphones through plastic tubing. This probe and tubing system has an internal transfer function which has been calculated both experimentally and theoretically. (This transfer function can be compensated for by a subroutine contained in the computer program.) It is important to realize that if the probe and tubing systems are identical, the coherence and phase lag relationships will not be altered by these internal transfer functions. The probe locations were varied both streamwise and radially for the data presented.

For the purpose of measuring fluctuating surface pressures, a 12 in. square plate was constructed with 0.04 in. diameter pressure sensing ports. These ports were arranged vertically, horizontally, and along both 45 angle lines about the center of the plate. The ports are located 5/16 in. apart (corresponding to 1/4 of the jet diameter) and extended outwards 1-7/8 in. (corresponding to 1-1/2 jet diameters). These ports were also connected to 1/8 in. B & K microphones, where

again the transfer functions have been calculated. The plate was varied both in the streamwise direction and in its angular orientation with the jet flow.

The output of a single pressure sensor was fed into a B & K spectrometer and strip chart recorder system. Two inputs were simultaneously input into a Nagra IV SJ tape recorder. The tape recorder was used because it gives a permanent record capability and has identical internal electronic transfer functions for both channels. The tape recorder output is input into a Federal Scientific UC 202B correlator and teletype, which gives a paper tape output. The paper tape is then fed into a CDC 6400 computer (containing the analysis program) giving an output from both a printer and a plotter.

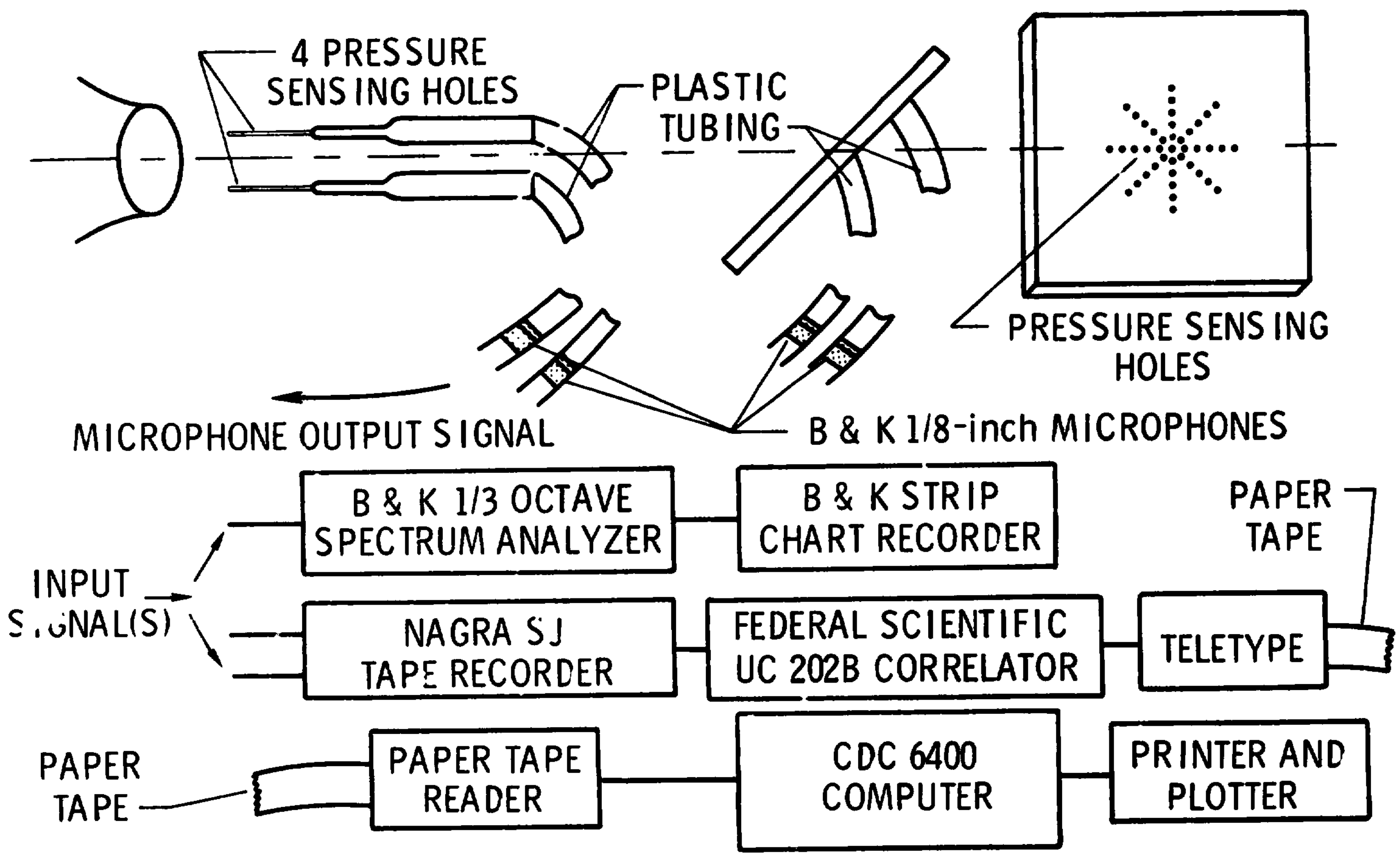


Figure 2.- Pressure sensors and instrumentation.

## COHERENCE AND PHASE LAG BEHIND FREE JET

(Figure 3)

The radial coherence and phase lag relationships behind the free jet are shown in figure 3. The jet exit velocity is 34.8 m/sec and the exit diameter is 3.17 cm. The rough sketch of the jet flow illustrates the structured turbulence model (refs. 1-6). In this model, the annular vortex tube formed by the jet, breaks up into individual vortex rings that convect downstream at some average spacing. These vortex rings coalesce as they travel downstream and eventually break up and become dominated by the surrounding turbulence.

Cross-correlation information was obtained from two probes simultaneously, one located on the jet centerline, the other located radially outward one half of a jet diameter. The coherences and phase lags calculated, at downstream locations of 2, 4, and 10 diameters, are plotted versus Strouhal number $(fD_j/U_j)$.

The phase lag remains approximately equal to zero throughout the frequency range in all three cases. This tends to suggest that the fluctuating pressure disturbances are being sensed simultaneously by both probes and that the disturbances are not propagating in the radial direction.

The coherence 2 diameters downstream is high throughout the frequency range, with a value near unity at Strouhal number of 0.4. At 4 diameters, the coherence is low except at a high coherence peak at a value of 0.4. The coherence is low everywhere at a downstream location of 10 diameters.

The vortex model of a jet predicts these high coherence peaks, at 2 and 4 diameters downstream, to be associated with vortex passage, with no apparent passage at 10 diameters where turbulence dominates.

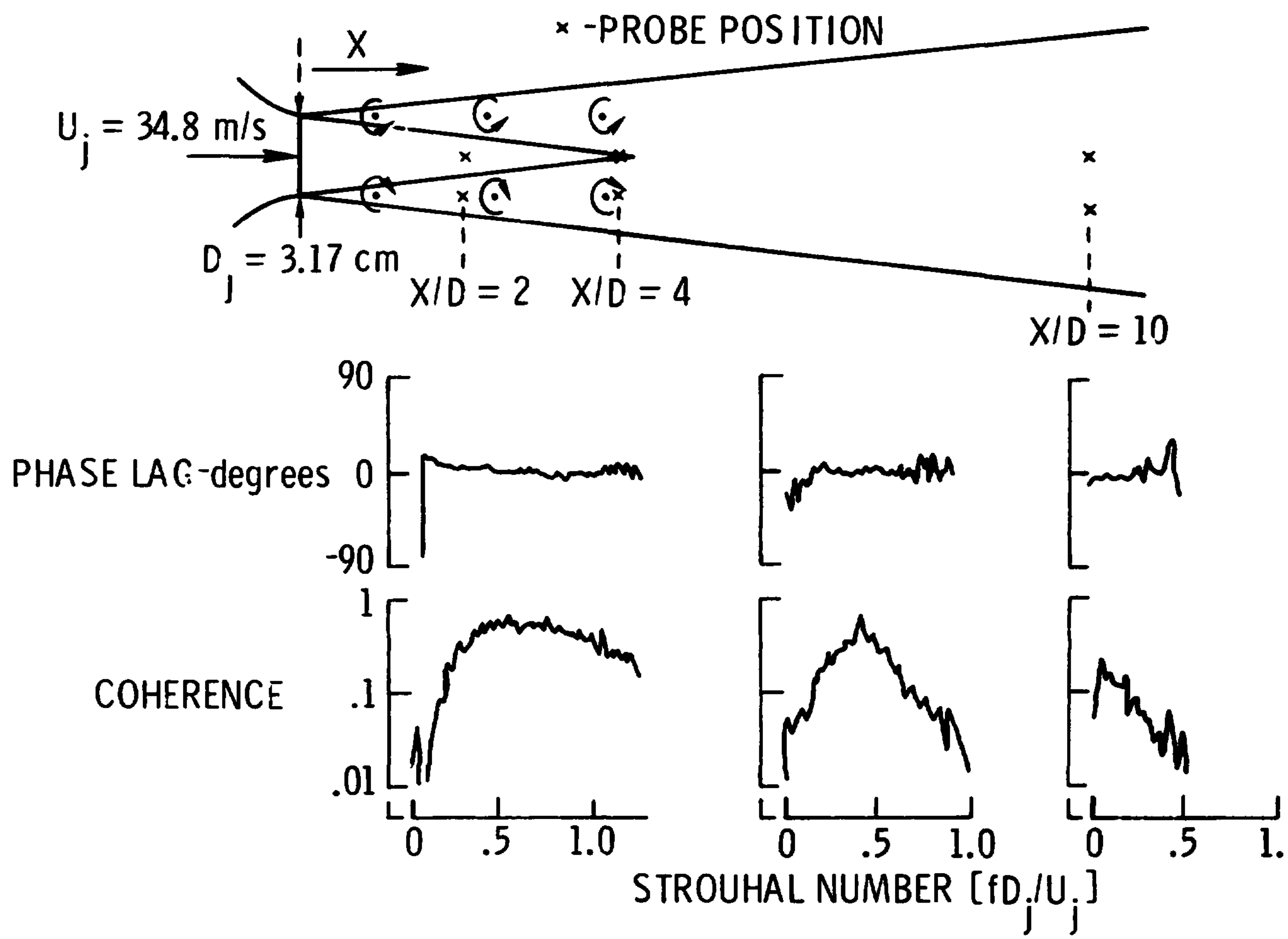


Figure [illegible].- Coherence and phase lag behind free jet.

## CONVECTION VELOCITIES

(Figure 4)

Figure 4 shows coherence and phase lag behind the free jet with the probes located next to each other radially, but with a 1 cm streamwise separation. Through cross-correlation techniques, the convection velocity of the pressure disturbances can be calculated.

The coherence is very high at all three locations, degenerating slightly with increased downstream location. The phase lag between the signals sensed at the two probes show a definite variance with frequency. The streamwise convection velocities calculated from these phase shift plots vary from 0.6 to 0.8 times the jet exit velocity. This demonstrates that the pressure distrubances are propagating downstream at relative convection speeds.

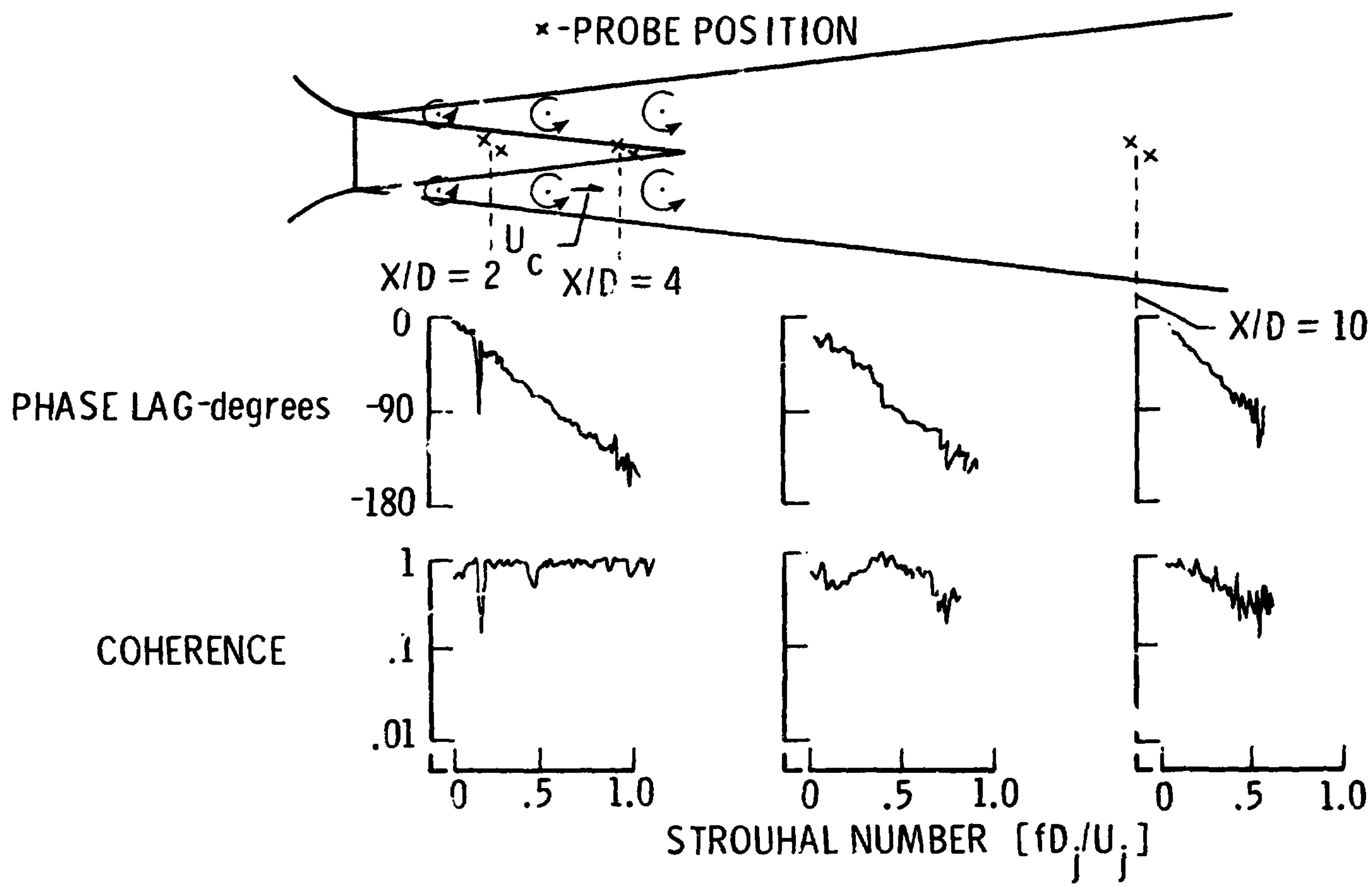


Figure 4.- Convection velocities.

## COHERENCE AND PHASE LAG ON FLAT PLATE

(Figure 5)

The coherence and phase lag relationships on a flat plate placed in the flow are shown in figure 5. The flat plate was placed in the jet flow with the plate centerpoint located 4 jet diameters downstream. The illustrated angles of plate inclination to the flow are 90°, 30°, and 0°. Two-point correlation data were calculated between the center of the plate and a port 1 jet diameter along the upstream jet centerline projection.

The coherence curves in the cases of 90° and 30° angular orientation still indicate a dominant frequency (St. No. = 0.4) as was the case in the free jet. The plate was found to acually enchance the dominance of this highly coherent frequency. In the case of 0° impingement, the coherence is found to be very high throughout the frequency range, indicating highly correlated pressure disturbance between these two points.

The phase lag curves show convection velocities that vary between 0.6 to 0.9 times the jet exit velocity, corresponding to induced flow along the plate. These values agree with convection velocities found in full-scale tests (ref. 7) and also values found in turbulent boundary layers.

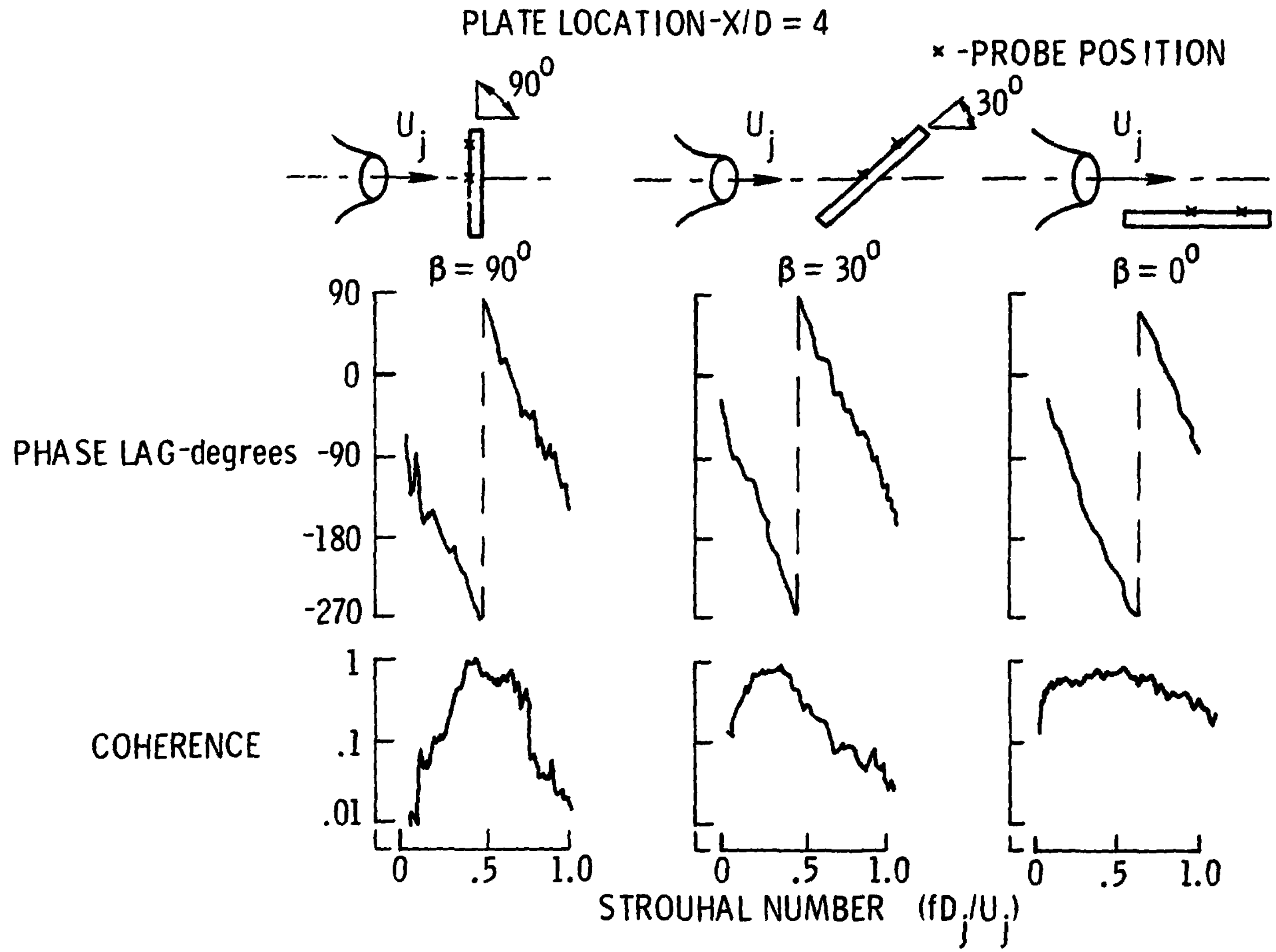


Figure 5.- Coherence and phase lag on flat plate.

## OVERALL $P_{rms}$ LEVELS

(Figure 6)

The overall surface fluctuating pressure levels on the flat plate at various downstream locations and angular orientations are shown in Figure 6. The locations of the center of the plate illustrated are at downstream locations of 2, 4, and 6 diameters for a jet inclination of 30°, and also angles of 90° (normal impingement) and 0° (grazing impingement) are shown at the 4 diameter downstream location. All $P_{rms}$ levels are given as fluctuating pressure coefficients defined as the ratio of the fluctuating pressure level to the jet exit dynamic pressure ($P_{rms}/q$). The measurements were taken outward from the center of the plate to 1-1/2 jet diameters along both the projected centerline of the jet and radially from this centerline projection.

The downstream variation, at 30° inclination, indicates that initially the potential core region is preserved at 2 and 4 diameters with peak fluctuations occurring within the sheared annulus region of the jet. The largest fluctuations are seen to occur in the upstream locations.

The variation in plate inclination angle, at 4 diameters downstream, indicates that the $P_{rms}$ levels tend to decrease with decreasing inclination angle. The levels are highest at the centerpoint of the plate for normal impingement. Grazing impingement gives the lowest overall levels with the upstream locations being only slightly higher than other plate locations. The levels in the radial direction begin to drop off quickly at the larger distances from the centerpoint indicating the edge of the jet and that the jet has little radial spreading induced by the presence of the plate.

These figures indicate that the problem area of high fluctuating pressures is in the upstream location. This is a complex region for induced flow down the plate and direct impingement flow proceeding up the plate are encountered. Also, the effect of increasing the impingement angle causes an increase in overall fluctuating pressure levels.

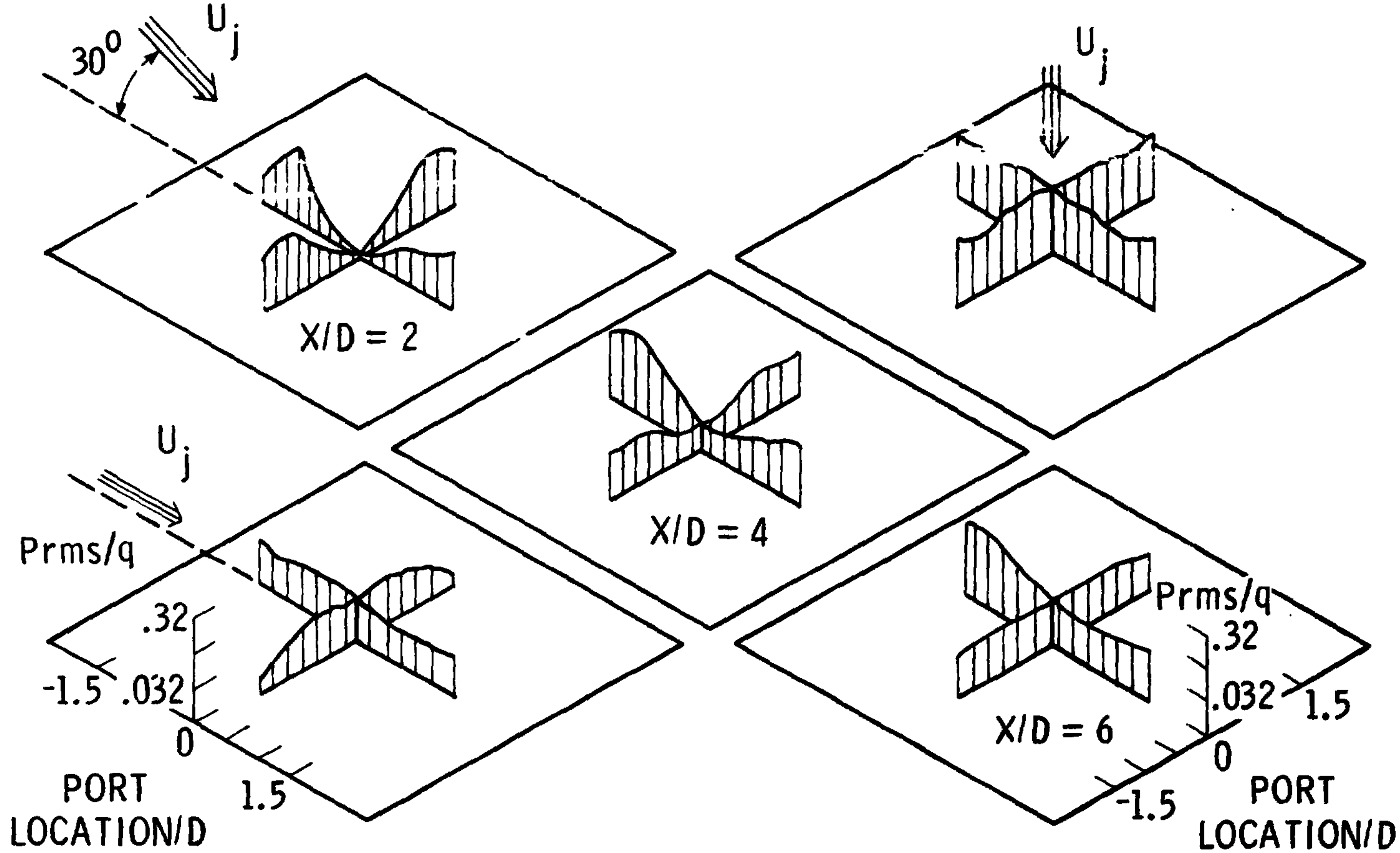


Figure 6.- Overall $P_{rms}$ levels.

## FLUCTUATING PRESSURE COEFFICIENT COMPARISONS

(Figure 7)

Figure 7 shows a comparison between the fluctuating pressure coefficients measured in this study and those measured on EBF and USB full-scale tests (ref. 8). The graphs are separated to show comparisons of varied plate angle measurements to EBF measurements, and the plate at grazing impingement to the USB configuration. The graphs indicate coefficient values are approximately the same for the model cases and the full-scale tests, and the coefficients are much higher with impingement as compared to a free jet.

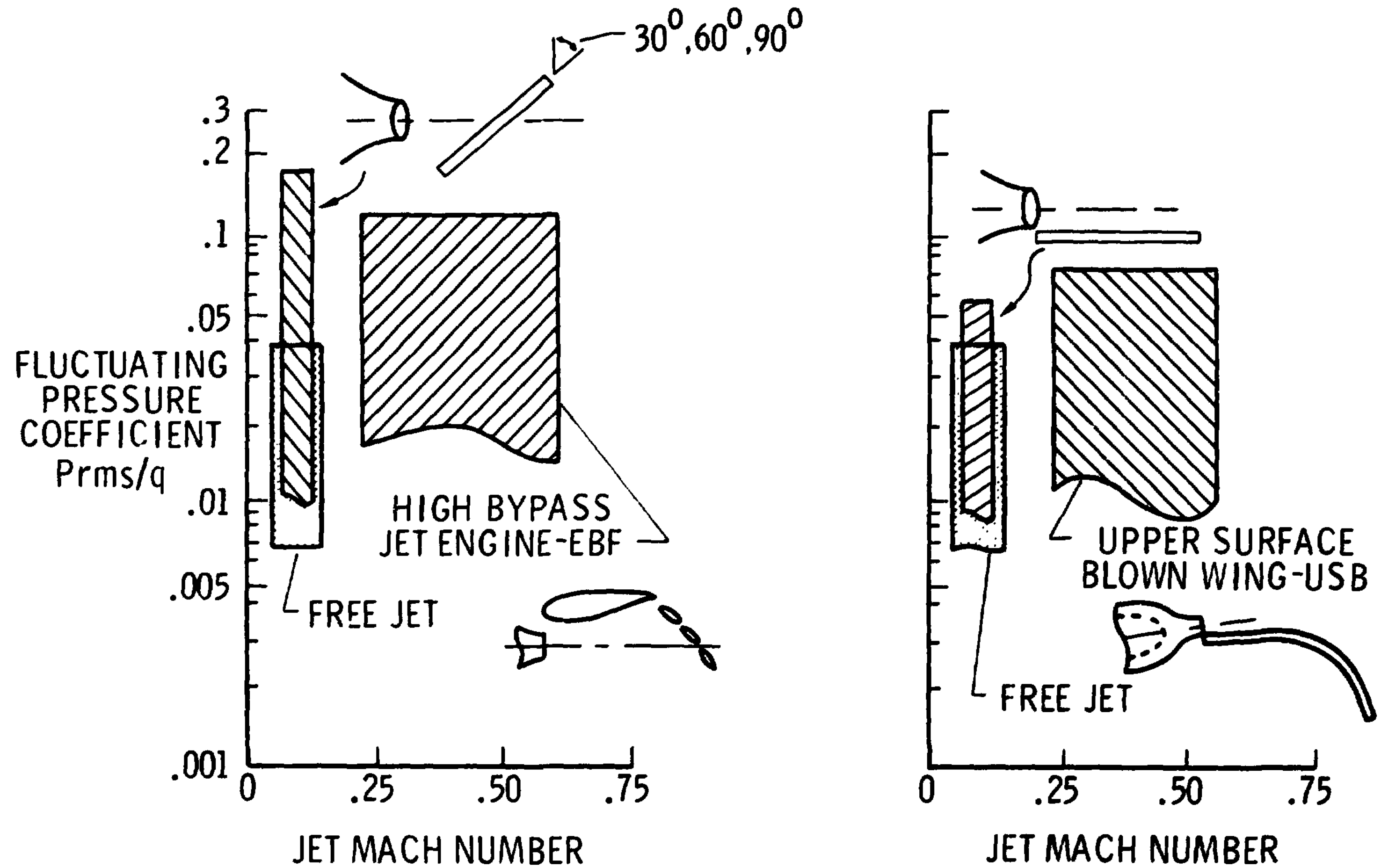


Figure 7.- Fluctuating pressure coefficient comparisons.

## SUMMARY

It was shown that the fluctuating pressure behavior in the near field of a free jet has a highly coherent frequency region and that the downstream convection speed of these distrubances varies between 0.6 and 0.8 times the jet exit velocity. When the flat plate was placed in the jet flow field, this coherent frequency region remained and the pressure fluctuations convected up the plate. The special case of grazing impingement showed a high coherence over the entire frequency range.

The highest fluctuating pressure levels were found in the upstream portion of the plate, because of the complex flow field formed by direct impingement and induced flow. The grazing impingement was found to have lowest $P_{rms}$ levels, however, this case has the highest overall coherence. The fluctuating pressure coefficients are about the same for these test cases as in the full-scale tests, with much higher coefficients than the free jet case.

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**16. Abstract**

The powered-lift configurations under present development for STOL aircraft are the externally-blown flap (EBF), involving direct jet impingement on the aircraft flaps, and the upper-surface blown (USB), where the jet flow is attached on the upper surface of the wing and directed downwards. Towards the goal of developing scaling laws to predict unsteady loads imposed on the structural components of these STOL aircraft from small model tests, the near field fluctuating pressure behavior for the simplified cases of a round free cold jet and the same jet impinging on a flat plate was investigated. This paper contains examples of coherences, phase lags (giving convection velocities) and overall fluctuating pressure levels measured. The fluctuating pressure levels measured on the flat plate are compared to surface fluctuating pressure levels measured on full-scale powered-lift configuration models.

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